28 FEBRUARY 1964 64-11 AFSCP 127-1

explosives SAFETY HANDBOOK

UNITED STATES AIR FORCE

AIR FORCE SYSTEMS COMMAND

PREFACE

There are numerous technical publications that deal with both the theory and practical use of explosives. Reports are available that furnish data gathered from research study and tests of the many agents and their properties categorized as explosives. In general, a broad knowledge of the sciences and engineering principles is necessary to appreciate and understand these publications. Many of them deal with theory and scientific terms above the knowledgeable level of the layman, even above the level of those frequently required to handle explosives and propellants. This is to be expected as the manufacture of explosives has become a highly technical and scientific endeavor, and latest developments have come from highly technical minds.

There now appears a need for an intermediate publication usable by Air Force personnel engaged in explosives activity at installation level who have not had opportunity for higher study. With this in view, the idea of this handbook was conceived. It is hoped that it will fill at least a partial need of those who have experienced difficulty in finding easily understood terminology and understanding of the basic facts about the explosive items they handle. It is desired also that this publication lend itself to a better understanding and appreciation for the many safety rules and precautions in effect and induce greater cooperation in support of precautions.

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HEADQUARTERS, AIR FORCE SYSTEMS COMMAND
Andrews Air Force Base, Washington, D. C.
28 February 1964

Ground Safety

EXPLOSIVE SAFETY HANDBOOK

The purpose of this pamphlet is to provide ready elementary basic facts about explosives, their ingredients, the hazards they possess, and guidance to workers to ward against hazards.

This publication shall not be construed to rescind, replace, or supersede any Air Force regulation, technical order, or manual dealing with explosives. It is intended to clarify and augment various terms and requirements found in manuals and technical orders and thus make them more meaningful. It is further desired to stimulate interest for deeper study into the properties of propellants and explosives. Without study one cannot hope to keep abreast of new developments and acquire the knowledge necessary for safe handling of future items.

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FOR THE COMMANDER:

UNITED STATES AIR FORCE
OFFICIAL
HQ AIR FORCE SYSTEMS COMMAND

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HISTORICAL BACKGROUND

The history of man's knowledge and use of explosives reaches back some nine centuries into early Chinese antiquity; however, there are a number of missing chapters in the history. For one thing, the discovery date is unknown; for another, circumstances surrounding early use are legendary; and moreover, the country of origin has never been established with certainty.

Various attempts have been made through research study of writings of the 14th and 15th centuries to determine above facts, but for reasons of inaccuracies in manuscripts, errors in translation, and fanciful style of writers in those days, they remain a matter of conjecture.

One Chinese "source" alleges that a material that was a forerunner of gunpowder was invented by the Chinese around the year 100 A.D. Greek writings would have us believe that gunpowder was a development from "Greek fire" used in the defense of Constantinople in 660 A.D. The earliest authentic use of "powder" or explosives, however, is furnished by Chinese pictures and writings depicting pyrotechnic devices for amusement around the year 1000 A.D. This has led to accrediting the Chinese with its discovery or invention.

From the above it can be concluded that the origin and early use of explosives remains a moot question that likely will never be satisfactorily answered. A reasonable assumption is that gunpowder came into existence through a series of experiences and incidents occurring in Asiatic countries covering several centuries. A writing by Roger Bacon about the year 1250 A.D. gives the formula for black powder, therefore we assume by that date its use was known in Europe.

Some 50 years later, according to tradition, Berthold Schwarz, a German monk and magician, employed a mixture of saltpeter, sulphur, and charcoal to produce "black magic." Apparently he exploited its use to the extent that he is credited with the invention of a gun for using this mixture. It is said that while demonstrating it he blew himself up.

It has been authenticated that the casting of cannons and the training of gunners was a thriving industry in Central Europe as early as the 14th century, and that opposing forces used cannons in the Battle of Crecy in 1346. This fact establishes that some form or type of explosive has been used for more than 600 years.

The use and manufacture of explosives spread from Asia to Europe and later to America. Through the years all enlightened countries have come to use them in some form or degree.

For centuries black powder was the principal explosive. It was cheap and easy to make, the required equipment was simple, raw ingredients were plentiful, technical requirements were not exacting and the time involved for processing and cure was short. Only within the last 100 years have the large number of explosive items come into being which are employed today, and our present highly sophisticated items have been developed within the last 50 years.

Less than a century ago explosive plants were small affairs, employing at most only a few dozen people, and storage was confined to a few small magazines. Two World Wars and succeeding world events have changed this. Today's production facilities are vast complexes, employing in many cases several thousand people, and production output demands hundreds of acres for storage. All this must be supported by extensive ground, water, and air transportation.

To most people the word "explosive" connotes destruction and unloosed destructive power; however, explosives can be, and are, harnessed to do worthwhile work and promote progress. Today large quantities of explosives are used in excavations, mining, and similar work. Explosive devices are used for aircraft motor starters, canopy and fuel tank ejectors, and for numerous quick acting devices in industry and commerce. Propellants, both liquid and solid, serve as the energy source for driving and guiding today's space vehicles and may in time enable man to reach other planets. Thus we can see that a nation's use and application of explosives and explosive devices is closely related to its economic, industrial, and political status.

Explosives are by nature inherently dangerous and possess potentials for sudden destruction. Normally, the raw ingredients that go into their manufacture offer hazards to both persons and property. In some cases the properties and hazards of materials may change in the course of manufacture, but at no stage can the materials or items be considered absolutely safe.

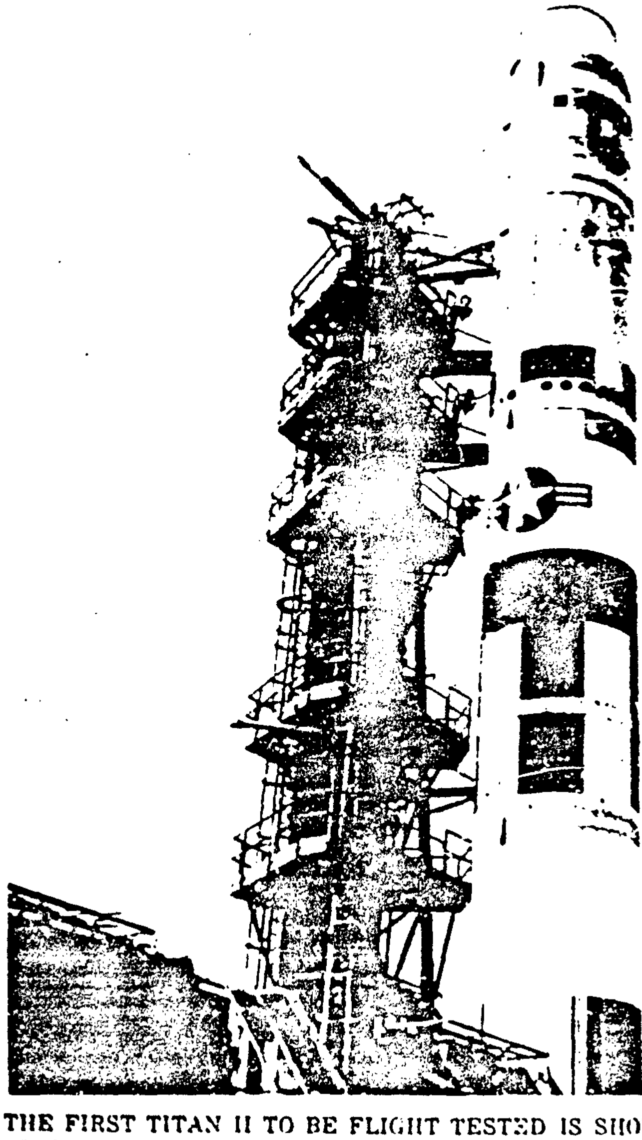
As an illustration, we need only take smokeless powder manufacture. We begin with a cellulose hydrocarbon (either cotton linters or wood pulp) and bring it in intimate contact with nitric and sulphuric acid. The cellulose is a fire hazard, the acids are toxic and corrosive. In the course of manufacture the acids are spent and washed out; thus the toxic corrosive agents are removed; however, the fire hazard remains, and is increased as alcohol and ether are introduced. One is an intoxicating agent, the other is an anesthetic. At this stage of manufacture, agents are added to stabilize the material and control the burning rate. These stabilizers are toxic and require special control measures. It is to be noted that during all this time, even though some hazardous properties are neutralized or removed, the fire hazard remains; in fact, it is increased to the extent that the burning rate is so rapid we call the material an explosive. As the process proceeds through solvent removal, drying, curing, and blending, the fire and explosive hazards remain.

We can see from the above that the manufacturing process is fraught with hazards at every step; and equipment design, process engineering, and work practices must be rigidly controlled. The least error or mistake can result in a disaster.

This example is made of a comparatively simple base-grain propellant and does not introduce many of the hazardous processes and extremely sensitive materials encountered in the manufacture of initiating compounds such as lead azide, mercury fulminate, lead styphnate, and finely ground black powder. High explosives such as tetryl, TNT, NG, RDX, and HMX present some hazard at every stage of manufacture and handling.

Until recent years, base-grain propellants such as black and smokeless powder were divided into fixed amounts and utilized in a gun as a propelling charge for a projective (bullet or shell). Latest developments have eliminated the need for a gun in many cases. Presently, the loose powder is further processed into a single large unit called a "rocket motor." This processing of base-grain material (single cylindrical grains 0.050" x 0.050") into a single grain rocket motor which may weigh several thousand pounds has introduced many new hazards.

Today man is wrestling with a whole new field of agents categorically referred to as explosives. Some are in solid form, some are liquid, others gases, while some change from one form to another in the course of use. Many pose hazards of an extreme nature, require most exacting processing techniques, and are made in exceedingly large quantities. A single present day solid rocket motor may contain as many as seven different explosives and exceed in tonnage all the powder expended in a major battle during the Spanish-American War. Scientists continue the search for ingredients that will process into finished items having even greater energy per unit weight than known today, yet remain within manufacture and use control. Safety is the underlying control factor and must be an integral part of processing and use.



THE FIRST TITAN II TO BE FLIGHT TESTED IS SHOWN ON ITS LAUNCH PAD AT CAPE KENNEDY ON 17 FEBUARY 1962, UNDERGOING PRE-LAUNCH CHECK-OUT PROCEDURES. THIS MISSILE WAS SUCCESSFULLY TEST FLOWN ON 16 MARCH 1962.

Chapter I

INTRODUCTION

1-1. Use of This Publication. This publication is primarily concerned with the manufacture, handling, and transportation of raw ingredients, bulk materials or finished items in the explosive or propellant category while in the hands or control of divisions, centers, and contract management regions of the Air Force Systems Command. It is applicable to items that are included in both liquid and solid propellants. It applies also to conventional items, such as small arms, complete gun rounds, CAD items, conventional initiation devices, conventional bursting charges, etc. It is directed for use by all persons involved with such items whether safety or operational.

1-2. AFSC Policy on Safety. It is Air Force Systems Command management policy to provide a wholesome, healthful, and safe environment for both military and civilian personnel. To this end it utilizes established and proven methods for protection of persons from known hazards insofar as funds and technological skills permit. It employs engineering design wherever practical to provide a safe work environment, but recognizes that engineering design alone will not preclude accidents and injuries. It assumes its responsibility for training workers to recognize hazards and to work in a safe and efficient manner, and for providing protective clothing, devices, and techniques to guard against hazards. It is management policy to require supervisory personnel to "act positively to elminiate potential accident hazards existing in operations under their supervision." It behooves each to so inform himself and work in such a manner that accidents and resultant injury and property damage will not occur.

1-3. References and Guides.

AFR 32-20	Responsibilities for Explosives Safety Program, and AFSC Supplement 1
AFR 127-4	Investigating and Reporting USAF Accident/Incidents
AFR 136-6	Ammunition and Explosive Materiel Quality Assurance
AFM 32-6	Explosives Safety Manual
AFM 32-3	Accident Prevention Handbook
AFM 160-39	The Handling and Storage of Liquid Propellants
AFR 86-6	Installation Planning and Development (Q-D Standards)
Mil-Std-444	Nomenclature and Definitions in the Ammunition Area
T.O. 11A-1-20	Ammunition General
T.O. 11A-1-40	Ordnance Safety Manual ORDM 7-221
T.O. 11C-1-6	General Safety Procedures for Missile Liquid Propellants

The above are the more pertinent Air Force explosive safety guides, and are not intended to be all inclusive on the subject. Among the more pertinent publications on the subject available from Commercial Sources are:

Handbook of Dangerous Materials, by Irving Sax.

Dangerous Properties of Industrial Materials, by Irving Sax.

The Condensed Chemical Dictionary, Fifth Edition.

Chemistry of Powder and Explosives, by Tenney L. Davis.

Toxic Solvents, by Ethel Browning.

Nitroparafins and Their Hazards, NBFU Research Report Number 12.

Chapter II

TERMINOLOGY AND EXPLANATION OF TERMS

2-1. Explosives and explosives materiel. All ammunition, biological and chemical fillers, demolition material, solid rocket motors, solid and liquid propellants, cartridges, pyrotechnics, mines, bombs, grenades, warheads of all types (excluding nuclear weapons), explosive elements of ejection and aircrew escape systems, assemblies, kits and devices containing explosive material.

2-2. Burning. The combustion of a fuel in combination with oxygen.

2-3. Deflagration. A very rapid and highly destructive burning that approaches explosion velocities with proportionate build-up of hot gas pressures. (It is often difficult to distinguish between deflagration and a low order explosion.)

2-4. Explosion. An explosion is an effect generally resulting from a vigorous chemical reaction (e.g., extremely rapid burning) that suddenly releases a large amount of heat, gas energy, and pressures at a rate up to 2,000 feet per second. It is accompanied by a loud report, considerable destructive effect, and probably flying objects. This is to be differentiated from a rupture of a pressure pipe, tank, or boiler.

2-5. Explosive. Any chemical compound or mechanical mixture that, under the influence of a flame, spark, or other means, undergoes a sudden chemical change (decomposition) with the liberation of energy in the form of heat, light, and is accompanied by a large volume of gases.

a. Low Explosive. A combustible material that decomposes rapidly, but does not normally detonate or propagate a detonation.

b. Primary Explosive. A very sensitive explosive composition used in primers, caps, or detonators to intiate a single explosion or a chain of explosive reactions.

c. High Explosive. See paragraph 2-8.

2-6. Propellant. A chemical compound or mechanical mixture which, through burning, produces gases at controlled rates that are used to exert necessary pressure or push to propel a projectile, missile or other device, usually at supersonic speed.

a. Propellants are classified as *solids* or *liquids* according to their physical state. In either state they are composed of a *fuel* and an *oxidizer*. Normally in solids the fuel and oxidizer are joined and handled as a single entity, while in liquids they are quite commonly retained as separate components until moment of use.

b. Propellants are also referred to at times as *single base*, *double base*, and *triple base*. These terms apply to the composition; *single*, referring to a propellant composed of a single propelling ingredient; *double*, to one having two propelling ingredients; and *triple*, to one having three. These terms are normally applied to solid propellants made from organic chemicals.

c. Modified Double Base Propellants are conventional double base explosive compositions containing additionally a composite formulation.

d. Propellants at times are referred to as monopropellants and bi-propellants. Again, these terms refer to composition. A monopropellant has a single propelling agent, while bi-propellants have two propelling (thrust producing) agents. These terms are normally used when speaking of liquid propellants.

e. Solid propellants are occasionally spoken of as *organics* or *composites*. Organics are propellants composed mainly of organic chemicals such as nitrocellulose, nitroglycerin, etc., the fuel and oxygen being joined chemically. Composites are made of chemicals such as polystyrene and ammonium perchlorate, joined through mixture. Usually they contain no nitrated organics such as nitrocellulose or nitroglycerin.

f. As normally used, propellants burn through a pre-established rate; however, most can be made to explode and even detonate. The intermediate ingredients are often explosives. For example, a solid containing organic intermediates may contain small particle size nitrocellulose, ammonium nitrate, nitroglycerin, or other materials which will detonate under certain conditions.

2-7. Detonation. A detonation is an extremely rapid and violent process with instantaneous release of chemical energy in the form of heat and gas pressures, and is accompanied by a shock wave of velocities exceeding 2,000 feet per second. It is characterized by a sudden disruptive effect evidenced by high fragmentation, great shattering, and generally deep cratering effect. Oftentimes the shock wave velocity ranges up to 30 and even 50 thousand feet per second and may exert pressures up to 4 million psi.

2-8. High Explosive. An explosive material which, when initiated, releases its energy at detonating velocities, hence has great shocking power and bursting strength. Such materials are employed in missile warheads, shells, demolition bombs, mines, etc. There are a wide variety of such materials having various and/or specific properties; however, all are characterized by rapid decomposition rate accompanied by shock and high brisance. The more common high explosives in the Air Force inventory are: TNT, tetryl, Comp. B, RDX, and NG.

2-9. Initiators. A device or agent designed to start a single or chain of actions that result in the terminal thrust of an explosive or propellant. Among those in common use are various squibs, primers, detonators, and igniters.

2-10. Detonator. An explosive device sensitive to electrical or mechanical impulse, used to initiate or set off a larger quantity of explosives.

2-11. Rocket Motor. A motor utilizing a solid propellant for power source.

2-12. Rocket Engine. A motor utilizing a liquid (or liquids) propellant for power source.

2-13. Squib. A small pyrotechnic device used to fire the igniter in a rocket, CAD, etc.

2-14. Extruded Rocket Motors. Rocket motors are produced by extrusion of solid material under high pressure through dies to form motors of specific size and shape. Normally, the extrusion process is confined to motors of 10" or less in diameter and not more than 5' in length.

2-15. Cast Rocket Motors. Motors produced by pouring a slurry, or paste mixture (of the propellant ingredients), into a mold and curing into a solid grain or motor. Another method is to fill mold with small particle size, dry propellant, then add a solvent that dissolves dry material and causes it to cure into a solid unit. These two methods are employed in the manufacture of large motors.

2-16. Nozzle. The opening through which exhaust gases escape during the firing of rocket motors or engines. Nozzles are designed to specific size, shape, etc., to give maximum thrust.

2-17. Thrust. The push or force generated by a propellant under controlled conditions.

2-18. Specific Impulse. Thrust in pounds divided by propellant burning rate in pounds per second.

2-19. Total Impulse. The thrust developed by the motor, multiplied by the burning time.

2-20. Rocket. A thrust producing system composed of motor case, propellant and nozzle. It may carry a guidance system and "payload."

2-21. Vertical Test Stand. A strong fixed structure or installation designed to hold and test rocket motors in a vertical position.

2-22. Horizontal Test Stand. A strong fixed structure or installation designed to hold and test rocket motors in a horizontal position.

2-23. JATO. An abbreviation for the term jet assisted take off.

2-24. Booster. The word has three meanings in explosive terminology:

a. The first stage of a rocket motor or engine.

b. JATO aircraft units.

c. Intermediate explosive charge between the detonator and bursting charge in a bomb, shell or similar device.

2-25. Sustainer. The second or successive stages of a motor that provides sustained momentum to the missile and carries it on toward the target.

2-26. Jet. The exhaust stream of gases through a pre-established nozzle, or the rapid flow of fluid through a small opening.

2-27. Jet Motor. A motor that provides forward propulsive force by producing rearward ejected gases.

2-28. Jet Horsepower. The horsepower produced by the rearward thrust of a jet engine or motor. It is a product of the volume of fuel times the burning rate.

2-29. Guided Missile. An unmanned vehicle moving out away from the earth's surface whose trajectory or flight path may be changed or altered.

2-30. Guided Missile Terminology.

a. SSM	Surface-to-Surface Missile
b. ASM	Air-to-Surface Missile
c. SAM	Surface-to-Air Missile
d. AAM	Air-to-Air Missile
e. WWM	Water-to-Water Missile
f. AUM	Air-to-Underwater Missile
g. SUM	Surface-to-Underwater Missile
h. UAM	Underwater-to-Air Missile
i. USM	Underwater-to-Surface Missile
j. "X"	Missile in experimental stage
k. "Y"	Missile in service test stage
l. "Z"	Missile is obsolete
m. "TV"	Test vehicle
n. GAR	Guided Aircraft Rocket
o. GAM	Guided Aircraft Missile
p. TM	Tactical Missile
q. SM	Strategic Missile
r. IM	Interceptor Missile

2-31. CAD. Cartridge-Actuated-Device is a small packaged device designed to perform a specific function. It is composed of a metal (usually) case which contains an initiator and actuator.

2-32. HE. An abbrevation for high explosive.

2-33. HEI. An abbreviation for high explosive incendiary.

2-34. Warhead. The portion of a shell or missile useful against a target; normally the case, firing device, and filler (explosive, incendiary, or chemical agent).

2-35. Round of Ammunition. A complete unit of ammunition composed of case, initiator-igniter, propellant and projectile (warhead). The term is usually applied to a round fired in a gun or a complete missile.

2-36. Pyrotechnic. A mild burning-explosive composition designed to produce smoke or specially colored lights for screens, flares, or signals. The ingredients in the composition predetermine the effects resulting from burning. Such materials are packaged in containers designed for release from aircraft or for firing from a gun or missile.

2-37. Incendiary. A term applied to a burning composition designed to produce intense heat up to several seconds. The composition contains powdered metals which ignite and burn at temperature 2500° F. and up.

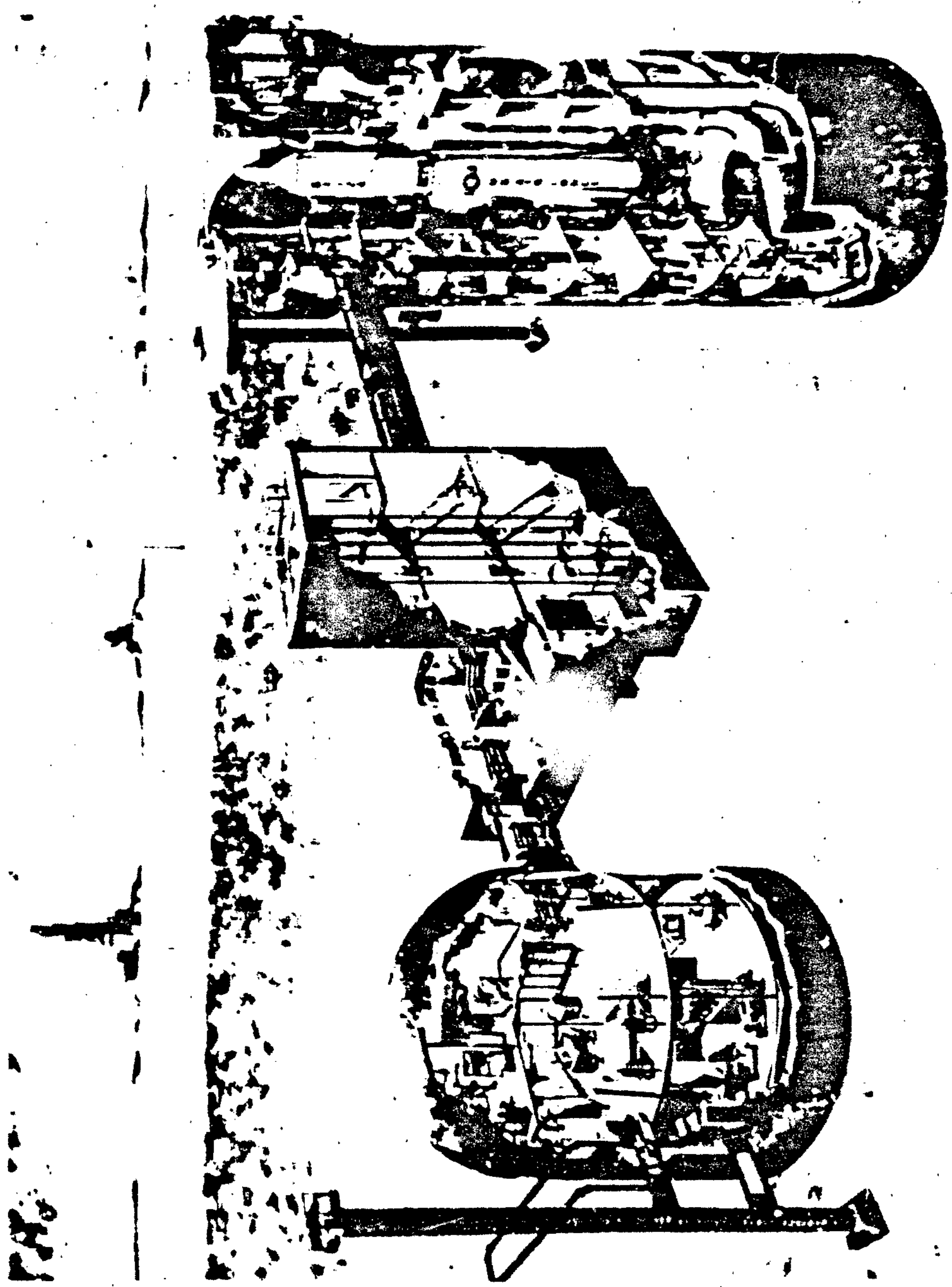
2-38. Hypergolic. A term applied to the instantaneous ignition action of certain fuels and oxidizers upon contact with each other.

2-39. Hypergolic Mixtures. Mixtures of two or more materials which spontaneously ignite on coming together; for example, fuming nitric acid (oxidizer) and furfuryl alcohol (fuel).

2-40. Simultaneous Detonation. The detonation of two separate quantities of explosives occurring so nearly at the same time that they cannot be detected by sound or effect as being separate. In such incidents, one explosion usually sets the other off by shock wave.

2-41. Deluge System. A special fire protection system designed to immediately release a large volume of water to prevent catastrophic destruction from fire or explosion. Deluge systems are differentiated from sprinkler systems by the volume of water they release, the special control valves employed, and the sensing devices or detectors. Latest design for propellant works is to install detectors that function on "rate of rise" principle within .5 seconds, and deliver copious quantities of water to absorb heat generated by burning propellant, and thus slow the burning rate. This thinking is opposed to that advocated in the past; namely, that water would extinguish burning explosives. Many of the newer formulations cannot be extinguished by water alone.

2-42. Adiabatic. A process, condition, or operation during which there is no gain or loss of heat from the surroundings (outside). Adiabatic action is occasionally stated as the cause of an explosion for reason that during mixing and pressing, internal heat may build up and localize without transfer, resulting in temperature at one spot reaching ignition level. Compression of materials raises temperatures and if the heat is trapped inside without opportunity to escape, an explosion will likely follow.



ARTIST CONCEPT OF A COMPLETED COMPLEX

Chapter III

PROPELLANTS—EXPLOSIVES—HAZARDS

3-1. Basic Requirements for Propellants and Explosives.

a. Raw ingredients be readily available in large quantities, relatively cheap in price, and processable with reasonable safety.

b. Finished items must be of a type that are uniform in size, shape, etc., and possess uniform response characteristics.

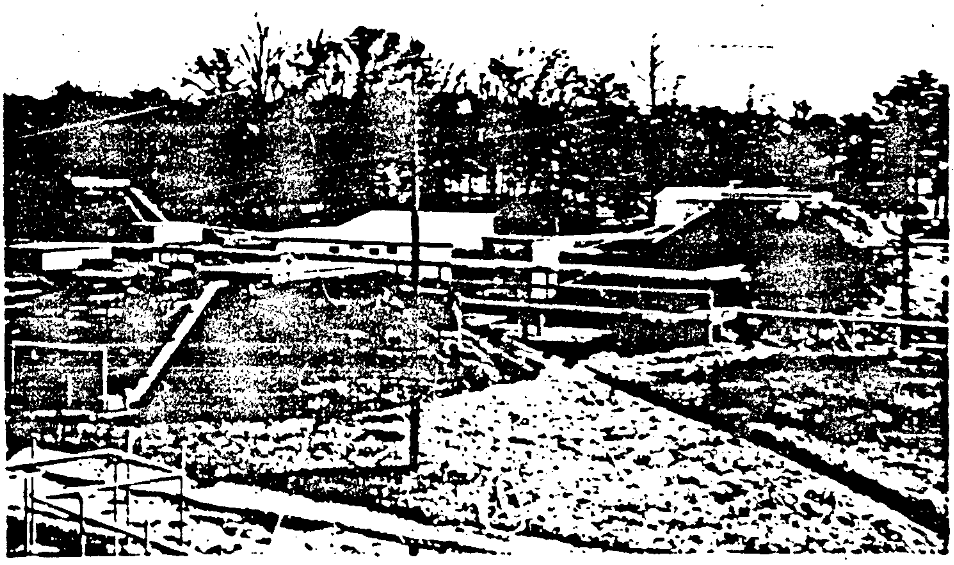
c. Possess stability during handling, transportation, and storage.

d. Items must remain stable under normal temperature changes.

e. Items, on initiation, must deliver large quantities of gas and heat in optimum time.

f. High pressure must result from the sudden decomposition (explosion) of the substance.

g. Waste and residue remaining from decomposition must be minimum.



REMOTELY OPERATED MIXING AND PRESS BUILDING PROTECTED BY EARTH MOUNDS. NOTE: VENT TYPE ROOF-TUNNEL ENTRANCES ARE PROTECTED BY HEAVY SPECIALLY DESIGNED DOORS.

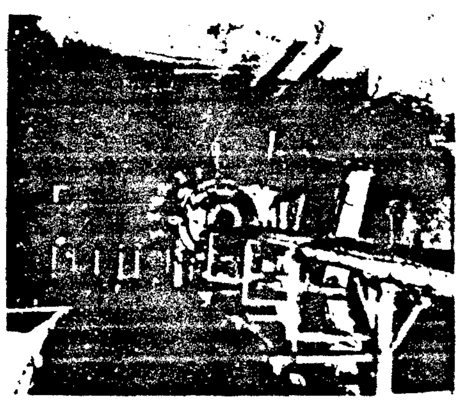
3-2. Hazardous Properties of Explosives and Ingredients.

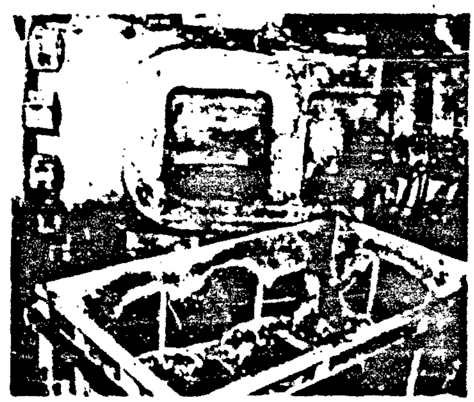
a. All explosives are in some degree susceptible to initiation and decomposition (burning or explosion) by flame, friction, or impact. The degree of sensitivity and response to these ignition sources varies with the chemical composition, particle size, and state of confinement. Black powder burns with a flame when unconfined and explodes when confined, the rate being proportionate to particle size. Smokeless powder normally burns rapidly when ignited in the open; under confinement it may deflagrate or even detonate depending on particle size and strength of container. Other explosives only burn when unconfined, some very slowly and with difficulty when spread in the open, but react quite differently when confined. TNT, Explosive D, ammonium nitrate, nitroglycerin, nitroguanidine, and composite explosives are relatively slow burning in the open, however under confinement they detonate if exposed to appreciable heat and shock. Some primary explosives do not burn, in fact are not combustible, but are extremely sensitive to heat, impact, friction, and electrical impulse. Propellants/explosives cast into solid rocket motors normally burn but may explode in certain configurations, or if voids or cracks develop in motor during the casting or curing process.

b. Explosives ingredients also have their specific hazardous properties. Some are toxic, producing dermatitis on regular contact with the skin; some are respiratory irritants and the fumes or dust therefrom are harmful to breathe. The halogen compounds, the boron hydrides, and the beryllium compounds are extremely toxic and exposure to even small concentrations can be fatal. Zirconium powder or dust is extremely sensitive to static electricity. Perchlorates are unstable in the presence of oils, greases, and similar fuels. Alcohol, ether, acetone, amyl acetate, nitric acid, DNT, ethyl centralite, and resorcinol are both toxic and flammable.

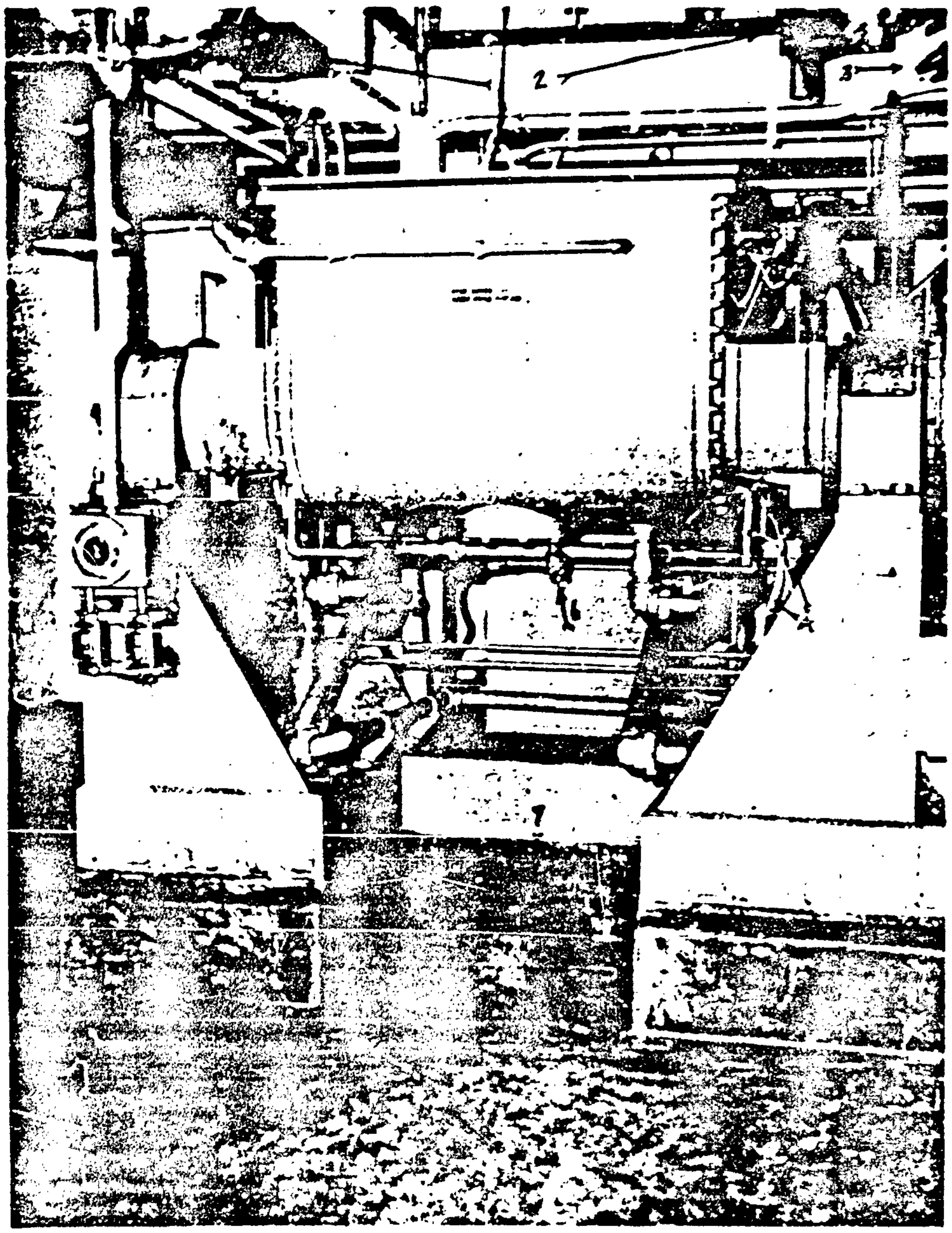
c. In summary, most explosive ingredients possess toxic properties to some degree. Many are highly flammable, some are extremely reactive in the presence of other agents, and *all* are chemically affected by heat. During manufacture and processing, rigid controls must be exercised to provide protection to workers from toxic properties and to prevent fires and explosions from heat, static electricity, or rough handling.

d. Primary explosive and booster material manufacture pose extreme hazards, chief of which are mixing and pressing. These two are performed remotely behind protective shields or barricades. In the manufacture of high explosives the initial mixing process is really one of nitration which may result in fume-offs and fires if not rigidly controlled.





RESULTS OF FIRES DURING EXPLOSIVE MANUFACTURE.



PROPELLANT MIXER. NOTE: (1) EXPLOSION PROOF ELECTRIC CONTROLS; (2) FLAME DETECTORS; (3) DELUGE HEADS; (4) PIPING GROUND WIRES; (6) TEMPERATURE SENSOR FOR MIX; (7) PORT TO CASTING PIT.

e. On completion of nitration, the material moves on through neutralization and washing processes which are comparatively safe for most explosives.

f. It should be recognized that in almost all explosives manufacture and processing there are one or more stages where explosive vapors or dusts are present. In such places, nonsparking tools, explosion proof electrical fixtures, and both equipment and personnel grounding are imperative if incidents are to be avoided.

3-3. Manufacturing Hazards.

a. The manufacture of explosives requires many and varied steps and processes according to the specific ingredients and finished item. A discussion of them all is beyond the scope of this publication; in fact, would require volumes. Only the more general operations and operational hazards will be touched on here.

b. The production of any successful explosive requires the incorporation of two or more ingredients. This operational step is carried out in a vessel referred to as a mixer. Raw ingredients are generally unstable in the presence of each other until the final stage of mixing; therefore, the mixing process is a tricky one that requires temperature control and quite often humidity control. The likelihood of a violent reaction during mixing has led, in most cases to operation by "remote control," which simply means the operator is located some distance away in a protected area and handles the adding of materials and mixing by "push button" controls, using mirrors, viewports or TV, to observe. As raw ingredients are added, automatic devices sense danger temperatures, etc., and make adjustments to correct conditions. Mechanically powered paddles, or blades, synchronized to bring all materials in intimate contact with each other within a fixed time cycle are employed to give uniform mix. Blades must be designed to prevent any scraping or pinching action, otherwise a fire or explosion may result.

c. On completion of the mixing cycle, successive steps vary with materials and use. In some cases, the mixed material is cast directly into a mold and cured; in other cases, it is pressed to remove waste liquids, and shaped for later processing; in still other cases, it is extruded into fixed shape and size by use of huge hydraulic presses that operate at pressures up to 3000 psi. Pressing operations are hazardous and should be properly barricaded and performed by remote control.

d. Both cast and extruded rocket motors require sawing, trimming or other machining operations. These are hazardous processes that should be performed by remote control. Safe machining requires a coolant, such as water, nitrogen gas or cool air, on the cutting tool to keep temperatures within control limits. High speed, large volume deluge systems should protect machining operations to slow down burning and minimize damage in event of fire.

e. Core or mandrel removal from cast motors is another operation that has been a source of fires/explosions. Safe practices require that operation be performed under deluge protection with operators stationed at protected locations while core jacks and pullers are under tension.

f. Mixing, pressing, core removal and machining are considered the most hazardous operations in the manufacture of solid propellants, and rocket motors; however, other operations such as the screening of dry ingredients and the handling of solvents require precautions and care.

Chapter IV

COMMON EXPLOSIVES, THEIR MANUFACTURE AND USE

4-1. Black Powder.

a. The oldest acceptable explosive in use today is black powder. It is a mixture of three rather common materials—charcoal, saltpeter (sodium nitrate) and sulphur. The mixing operation is simple compared to that employed in mixing some of the more recently developed explosives. Prior to mixing, each of the three ingredients is purified, dried, and pulverized. They are then placed in a rotating wooden drum in a predetermined ratio, and as the drum revolves, mixing takes place. The mixture is then placed in a large stone vessel equipped with rotating wheels which lightly crush it into a cake on the bottom of the vessel. Several of these cakes are rolled together and pressed into a larger cake which is broken up and granulated into grains. The grains are then refined and coated with graphite in a tumbling drum. A screening process follows to segregate for particle size and remove dust and excess graphite.

b. Particle size is largely the determining factor in burning rate, the smaller the particle the faster it burns. Dust particle size may burn at rates approaching detonation velocity.

c. For several centuries black powder was the chief explosive and served many purposes. The military services used large grains for cannon propellants due to its slower rate of burning, smaller grains were used in shoulder and side arms while even smaller grains (dust particle size) were used for ignition purposes, demolition work, and for shell bursting charges. Two primary disadvantages associated with the use of black powder are: it burns with a heavy black smoke; and, when handled it tends to erode away into smaller grain size and gives off a black dust which is messy and extremely dangerous.

d. Another undesirable property of black powder is its extreme sensitivity to friction, spark, and open-flame. This necessitates the utmost caution to avoid crushing, pinching, and the generation of static electricity. Safety for open handling, packing, etc., necessitates that equipment such as tables, benches, scales, and containers be electrically grounded and that floors be conductive. Employees should wear conductive shoes, cotton underclothing, flameproof uniforms and head coverings. All tools should be of the non-sparking type. Operating bays should be equipped with explosion proof electric fixtures and deluge systems. Any material spilled should be promptly cleaned up and placed in an appropriately labeled, covered container, partially filled with water.

e. Black powder has been replaced as a demolition agent and propellant by less hazardous and otherwise more desirable agents. Its use in the military service today is largely confined to igniters and as an ingredient in pyrotechnic devices.

4-2. Smokeless Powder.

a. About the middle of the 19th century it was discovered that the nitration of certain organic compounds would produce explosives. Experimental studies led to the development of smokeless powder; first successfully used in Prussia in 1861. The early manufacturing process was to nitrate wood, then impregnate it in saltpeter, and dry. This method soon gave way to the process of nitrating cotton linters, then dissolving nitrated mass in a mixture of alcohol and ether before extruding through dies to desired size and shape.

b. This powder offered a number of advantages over conventional black powder as a propellant. For one thing, the volume of smoke was greatly reduced; it was less sensitive to friction, heat, and static; and it burned cleaner and left little residue in the gun barrel.

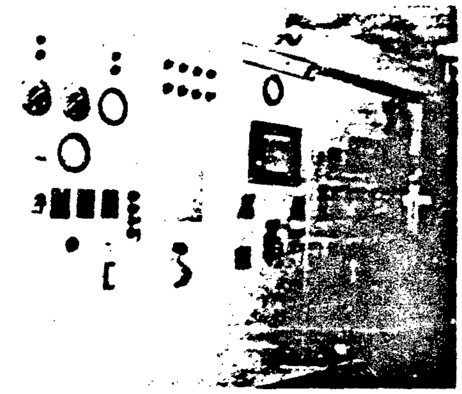
c. Today's technique is a highly refined process that is much safer to carry out than was ever perfected for black powder. It requires the nitration of refined cotton linters by concentrated nitric acid employing sulphuric acid as a catalyst. On completion of nitration, the residual acid is removed through boiling, poaching, and pulping. Successive steps remove the water by pressing and alcohol dehydration. The material is converted to a colloid by dissolving in ether after which it can be pressed and extruded to uniform grain size.

d. Successive steps remove excess solvent and cure into finished stable grains with definite properties. Blending, screening, and packing operations follow after which powder is ready for use or storage.

e. Present quality control techniques enable manufacturers to produce powders with such special properties as "flashless," "nonhydroscopic," "controlled burning time rate," "progressive burning nature," "delayed pressure build-up," etc. Conventional grain shape is cylindrical, either single or multiperforated; however, other shapes such as slivers, discs, and spheres are sometimes employed.

f. Smokeless powder produced in the above manner is referred to as single base powder, single base propellant, and as base grain propellant.

g. The nitration described above involves a mixing which brings about a chemical change. This process frequently results in acid leaks, spills, "fume offs," and fires. Protection from these hazards demand eye, face, head, and hand protection, flame-proof acid resisting coveralls, and safety showers.



CONTROL PANEL IN OPERATOR'S PROTECTIVE SHELTER ENABLES HIM TO HANDLE PRESS LOCATED UNDERGROUND A SAFE DISTANCE AWAY.

h. Smokeless powder's main use from its earliest development through World War II was for gun propellants. The bulk of todays production goes into the manufacture of solid rocket motors.

4-3. Nitroglycerin.

a. The Italian scientist Sobrero discovered nitroglycerin about the middle of the 19th century and built a plant for its manufacture. The adventure was not successful because of continuous explosions. Later, while employed by the Nobel Swedish firm, Sobrero permitted Nobel to experiment with his patent. After several disastrous explosions, Nobel developed a method for incorporating the liquid into a solid which came to be known as dynamite. The added solid material (earth & sawdust) acted as a desensitizer and made the material relatively safe; yet, by employing a detonater or blasting cap it could be exploded at high order.

b. Nitroglycerin has been one of the most satisfactory "high explosives." Its manufacture involves a very dangerous process, and over the years has caused many disasterous incidents. Nitroglycerin, or NG as it is most often called, is manufactured by adding mixed concentrated nitric and sulphuric acid to pure glycerol oil. The process is called nitration and is accompanied by a boiling reaction that is extremely hazardous and requires careful temperature control. The nitrating vessel is equipped with stirring paddles and cooling coils. The temperature is controlled by an operator regulating the rate of cold water flow through coils. Without this control, the process can quickly get out of hand and result in a fire or explosion.

c. On completion of nitration, the spent acid is drained off and the material is passed through a series of vessels in which it is washed and refined. The raw NG, a viscous liquid resembling castor oil, is so sensitive to shock that it is conveyed through rubber lined pipes to the desensitizing building where agents are added to reduce its sensitivity.

d. NG manufacture is a process that accepts no mistakes or errors. Each step of the operation must be rigidly controlled, thus automatic fail-safe devices are employed to shut operation down in event anything goes wrong. Buildings are designed for only one operational step, and equipment employing moving parts is avoided following the nitration process. All floors, steps, and inside walkways are lead covered; walls and ceilings are finished with nonporous surfaces free of cracks and crevices, and indirect lighting from locations outside bays is employed. Material transfer is by gravity or air jet through rubber lined troughs free of joints and rough surfaces. Any handling is in special rubber buckets or rubber containers fixed on a rubber-tired hand cart, appropriately referred to as an "Angel Buggy." NG is usually processed into finished items such as dynamite, propellant, etc., at the plant where manufactured as Interstate Commerce Commission (ICC) regulations do not permit transfer of liquid NG over railroad or highway except by special permission. Within plant, transfer in specially designed vessels called dessicators, is permissible after desensitization. In present day programs, millions of pounds of NG are incorporated in solid rocket motors, and gas generators for pressure actuated devices.

4-4. Composites.

a. Composite propellants (explosives) are products of the newer explosive formulations that have come into prominence and wide application since World War II. They are manufactured by the physical mixture of either a solid or liquid fuel and an oxidizer, usually employing a binding agent. Several formulations call for a synthetic resin fuel to which is added pulverized aluminum. Formulations may call for powdered magnesium, zirconium, beryllium, etc., as additives. In fact, experimental studies have utilized most potential energy source materials. Ammonium perchlorate is the widely accepted oxidizing agent, although potassium perchlorate, various chlorates, nitrates, etc., have been employed. The basic ingredients in a commonly accepted formula are synthetic rubber for fuel and ammonium perchlorate for oxidizer.

b. Composite formulas are mixed in a conventional mixer under rigid process control, then are cast into molds, cured and machined to finished dimensions. The manufacturing process sound much easier and safer than it is. In reality it offers many complicated and perplexing problems; however, composite rocket motors have proven practical and have much to offer. They are relatively safer and cheaper to manufacture than those made from the older nitrated propellants such as NC, NG, and NQ, and their combinations.

4-5. Primary Explosives.

a. Primary explosives are those used as initiating agents and are frequently referred to as priming compositions, thus the conventional term "primer." Among the priming compositions in ordinary usage are lead azide, mercury fulminate, lead styphnate, tetracene, PETN, DDNP, finely divided black powder, potassium nitrate and sodium nitrate.

b. Priming compositions are prepared by

physically mixing chemicals that are inordinately sensitive to impact and friction when in combination, and when exploded disintegrate instantaneously, releasing hot gases and minute incandescent particles. They are high explosives with extremely sensitive characteristics, yet possess distinctively lower brisance values than the materials they are used to detonate. Many known priming compositions are too sensitive and unstable for practical use. Those acceptable are produced in very small lots due to hazards encountered in manufacture. Any storage of the more sensitive compositions is under water or other desensitizing agent.

c. Primers or detonators are manufactured to special size, strength, and sensitivity to meet use demands. Strength and sensitivity requirements are met by blending different compositions. Frequently ground glass or corbordundum is added to compositions that go into the make up of percussion elements to provide friction characteristics that assure positive ignition.

4-6. Pyrotechnics.

a. The word *pyrotechnic* is of ancient origin and is derived from the combination of *pyro* meaning fire or to burn, and *technic* meaning artful use of. For many years it seems to have applied to fireworks used for display and amusement. From a present day military standpoint, it applies to materials or items used for producing smoke screens, smoke signals, flares for signals, flares for illumination, tracer compositions, and in some cases, for producing extremely high temperatures as in the case of incendiary bombs.

b. Pyrotechnic compositions are designed for special purposes and effect which is brought about by the individual chemical additives in the burning mixture. For example, if brilliant high candle power illumination is desired, additives of powdered aluminum and magnesium are incorporated. If red colored lights are required, percentages of strontium nitrate are added; barium nitrate additives give green colored lights; cupric oxide in combination produces purple lights; thus, with the proper additives the whole spectrum of lights or smokes can be effected.

c. The basic ingredients in all pyrotechnic mixtures are the fuel and oxidizing agents. Materials are selected for a composition that produces a low explosive with a relatively slow burning rate and low energy release which is further reduced by retardants. The fascinating end product of the chemistry involved in the manufacture and use of pyrotechnics is dramatically demonstrated by Fourth of July fireworks displays; however, such displays never reveal the extensive scope made of them by the military services.

d. Pyrotechnic compositions employed for military service are packed in containers appropriate for use. Some are packed in rifle grenades, some in shells for tracer illuminants, some in canisters for release from aircraft, while others may be loaded into shells and bombs. Pyrotechnic loaded shells and bombs carry a bursting charge to rupture case before the release of pyrotechnic mixture.

4-7. High Explosives.

a. High explosives, as discussed earlier, possesses the characteristics of high brisance and destructive shock wave when initiated. They are manufactured by the nitration of various petroleum or coal tar derivatives and are used for bursting charges and demolition work.

b. Nitration is a chemical change that takes place when nitric acid acts on certain other materials. It is speeded up by the addition of sulphuric acid which acts as a catalyst. The process is quite active and may become violent unless rigidly controlled. It is a fire-explosive hazardous process and the corrosive action of the strong acids envolved is a constant danger to piping, valves, tanks, etc., as well as to operating personnel. Special metals are required for equipment; building materials are usually acid and fire resistant; and, buildings are provided with special protective features such as deluge systems, strong dividing walls and explosion proof electric fixtures. Frequently buildings are barricaded from one another. Details of the various processes are beyond the scope of this handbook. Readers interested in further study can find technical publications that furnish necessary information pertaining to manufacture and use.

c. Among the more commonly used high explosives are:

(1) *TNT*—Manufactured by nitrating *toulene* in a three stage process. The finished product in flaked form resembles flaked Octagon soap and is quite stable and insensitive. TNT is used for bursting charges in shells, demolition bombs, grenades, etc. It requires a strong initiator but affords great destructive power when set off.

(2) *NG*—Manufactured by nitrating glycerol in a single stage process. It is a clear liquid resembling castor oil. Frequently, it is incorporated with substances to form less sensitive solids for demolition charges. It is more sensitive and less stable than TNT.

(3) *Explosive D*—Manufactured by neutralizing picric acid (a nitrated phenol) by means of ammonia. Explosive D is so insensitive that it can be detonated only with a powerful initiator. This property led to its use as shell and bomb fillers where deep penetration in concrete or steel is desired before detonation occurs.

(4) *Tetryl*—Manufactured by the nitration of benzine, reduction of the product by iron filings and muratic acid to aniline, then combined with wood alcohol under pressure, and renitrated. The finished product is a stable yellow crystalline powder that possess high explosive strength and brisance. It is used primarily for boosters of less sensitive explosives, and as a constituent of detonators.

(5) *Nitro starch*—Manufactured by nitrating ordinary starch which produces a white powdery material used for grenades and trench motors.

(6) *RDX*—Manufactured by a complicated process using TNT as a base material. RDX is more sensitive and possesses greater strength than TNT. Its use is for special demolition work, and as base ingredient for other high explosives.

(7) *Comp. A, A-2, and A-3*—Manufactured by granulation of RDX and coating with special desensitizing waxes.

(8) *Comp. B*—Manufactured by mixing RDX and TNT to pre-established percentages. It is more sensitive than TNT alone and possesses superior strength and brisance.

(9) *Comp. C-3, and C-4*—Manufactured by combining RDX with an oily plasticizer.

(10) *HMX*—Manufactured by multistage process of incorporating several other base explosives and refining to white crystalline solid that is extremely sensitive and possesses exceptionally high strength and brisance. In addition to its use as a high explosive for special conditions, it has gained some recognition as an ingredient in high impulse rocket motors.

(11) *Ammonal*—Composition of TNT, ammonium nitrate, and aluminum powder used for high brisant effect in motor shells.

(12) *Tritonal*—Composition of TNT and flaked aluminum used as high explosive bomb filler during World War II.

(13) *Amatol*—Composition of ammonium nitrate and TNT used during World War II as a substitute for straight TNT in demolition bombs.

(14) *Tetrytol*—Composition of tetryl and TNT for special purpose. Its sensitivity rests between straight tetryl and pure TNT.

(15) *Pentolite*—Composition of TNT and PETN for special grenades and boosters.

(16) *Torpex*—Composition of TNT, RDX and powdered aluminum developed for special blast effect in bombs and shells.

4-8. Liquid Propellants.

a. Liquid propellants fall into the category of explosives. Their use is an innovation of the guided missile and space age. Although liquid propellants normally burn, they possess explosive characteristics and may be expected to deflagrate and even explode under certain conditions. It is, therefore, extremely important that recognized control measures be exercised during handling and use to avoid disastrous incidents.

b. The fact that some liquid propellants will explode has generated a requirement for measuring their disruptive pressure strength in event of explosion. A rule-of-thumb yardstick that has come into acceptance is to refer to its "TNT Equivalent" which simply means that a certain quantity (pounds or tonnage) has the equivalent disruptive (explosive) strength of a given quantity of TNT. This might be stated as a proportion such as 3 to 1 which would be interpreted to mean that 3 pounds of the material would have the equivalent strength of 1 pound of TNT. Another way of stating the same fact would be to say the material had a 1/3 equivalency of TNT.

c. When speaking of liquid propellants, we refer to two different agents; one is a fuel, the other is an oxidizer. These are kept separate until the moment of use. This is the opposite of the solid propellants in which the fuel and oxidizer are joined in the mixing process.

d. Liquid propellants pose handling problems not experienced with solids. For one thing, separate storage facilities are required for fuels and oxidizers. Special tank cars and trucks are required for transfer. Liquids require tanks, piping, valves and pumps for materials up to point of use. In many cases, refrigeration and pressurizing are necessary for liquids. This creates the potential of leaks and spills. But the greatest hazard to operating personnel is the toxic or temperature effects from liquids. Most are highly volatile and toxic, thus must be handled in closed vessels to prevent build up of a respiratory hazardous environment. This is particularly true when nitrogen tetroxide, nitric acid, hydrogen peroxide, ammonia, aniline and hydrazine are handled. Hydrogen, oxygen, and nitrogen in the liquid state offer hazards of extremely low temperature that are deleterious to many metals and destroy body tissue of workers on contact.

e. Liquid propellants are manufactured by a standard commercial chemical process and in most cases are obtained from commercial suppliers. Their manufacture does not involve the explosive hazards accompanying the manufacture of most conventional military explosives.

f. Basic precautions to observe in handling and using liquid propellants are:

(1) Proper storage and separation of fuels and oxidizers.

(2) Compatible materials for storage and handling vessels.

(3) Good housekeeping at all times.

(4) Careful inspection of facilities and proper maintenance to minimize leaks and spills.

(5) Carefully trained operating personnel.

(6) Appropriate protective equipment and devices.

(7) Large quantities of water to handle spills, fires, etc.

4-9. Cartridge Actuated Devices (CADs).

a. Cartridge actuated devices (CAD) are small packaged units designed to function rapidly and accomplish a specific mission through development of gas pressure from a rocket motor. Their main use by the Air Force is for aircraft engine starting, ejection devices for aircraft canopies, emergency ejection of air crew members, release of fuel tanks, etc.

b. The small rocket motors used in CADs vary in size depending on amount of gas pressure required for the individual use. A typical motor approximately 1-inch in diameter and 6-inches long is manufactured by the extrusion of a solventless propellant into a cylindrical rod. The cylindrical rod is machined to exacting dimensions, and inserted into a close fitting aluminum cylinder equipped with a squib igniter. The unit is then closed, inspected and pressure tested for leaks in an inert gas and packaged for shipment to the using service.

c. CADs of other sizes and shapes are manufactured by a similar process. The motor in a CAD is not designed to explode, but to rapidly build up high gas pressures. Because of their positive quick action when ignited, they can cause personal injury and property damage if improperly handled. Their use has been a constant source of mishaps in and around aircraft. Investigations of these mishaps reveal that the major cause is the personal errors of handlers and not the malfunctioning of the devices themselves. CADs should be handled and used only by carefully trained, conscientious persons following in detail each step of well developed established procedure(s). Safety devices such as safety pins, streamers, etc., should be fully utilized.

Chapter V

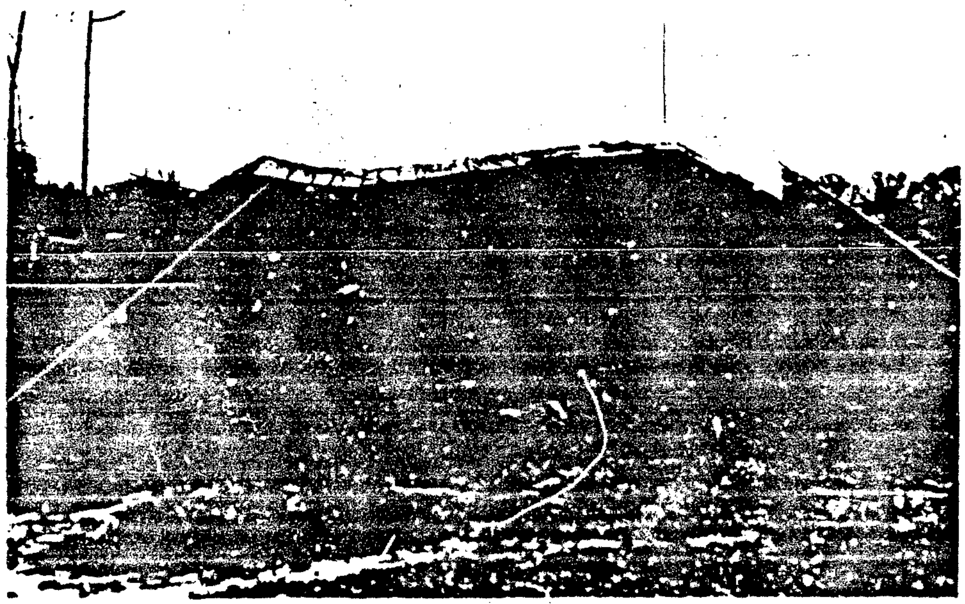
SPECIAL FACILITIES AND PROBLEMS

5-1. Facilities or Features. There are several facilities or features involved in the manufacture, handling and storage of propellants and explosives that appear to warrant mention. These are briefly discussed in the light of present day acceptance and regulatory control.

5-2. Quantity-Distances. Quantity-Distances are distances between a given quantity of explosives and another point (inhabited building, public road on another quantity of explosives) which will afford certain type protection in event of fire/explosion at the explosive site. These distances are listed and described as:

a. *Inhabited Building Distance* is the distance required between a building occupied by people (inhabited) and a given quantity of explosive that will afford protection to the building against "substantial structural damage if explosive goes off." The explosion might cause some cracks in walls, broken windows and the like, but would leave building standing, structurally sound, and occupants free of major injuries.

b. *Public Railway and Highway Distance* is the distance required between a road or



STRONG WALLS BACKED BY EARTH MOUNDS PROTECTED BUILDINGS AND OPERATIONS NEARBY, WHEN EXPLOSION OCCURRED.

railroad and a given quantity of explosive to afford protection to vehicles from blast effect in event explosive "goes off." It is figured at 60 percent of the Inhabited Building Distance. This lesser distance is justified by smaller size and nature of a rail or motor car.

c. *Intraline Distance* is the distance required between any two buildings within one operating line to prevent an explosion in one building setting off an explosion in the other from the *blast effect*. This distance would not protect against substantial structural damage, nor against another explosion initiated by flying missiles.

d. *Magazine Distance* is the required distance between two magazines that may be expected to prevent an explosion in one, initiating an explosion in the other from blast.

Discussion: Tables of distances are based on findings from investigations of explosions that have occurred during the past century. They were first developed by the state of NewJersey, were later accepted by the state of Delaware and have now come to have general acceptance throughout the country under title of American Table of Distances. Under the direction and sponsorship of the Armed Services Explosives Safety Board, additional studies and tests have been conducted and application extended to include new items as developed. The tables used by armed services today are referred to as Quantity-Distance Tables and are applied by all three services to the manufacture, transportation, and storage of explosives wherever the U.S. is involved.

Over the years experience has generally supported the validity of the tables as first written; in fact, has proven them so reliable that accepted formulas have been developed therefrom.

The application of Quantity-Distance Tables is a major factor in minimizing damage from explosions. They establish minimum distances that may be expected to prevent propogation of explosions from one point or site to an adjacent site by fire, blast and shock effect. Propagation of an explosion from one site to another by a missile or missiles is unlikely, though not improbable.

Quantity-Distance application must be associated and interpreted with classes of ammunition, the existence of intervening barricades and the location of explosives, either under or above ground.

5-3. Classes of Explosives. Explosives are divided into categories referred to as classes for convenience in establishing safety controls. Items possessing common properties and hazards are placed in a given class. This simplifies control techniques, minimizes cost of manufacture, handling, storage, and provides for greater safety. There are two commonly accepted classifications of explosives; the *ICC Classification* (Interstate Commerce Commission), and the *Department of Defense (DOD) Classification*.

a. The ICC is concerned with the transportation of explosives over public highways, railroads, and air and has established three classes, namely: (1) *Class A*, which is given to high order explosives (generally mass detonating) such as TNT, NG, tetryl, RDX, HMX, etc.; (2) *Class B*, given to propellants and explosive items that may be expected to burn if ignited during transportation; and (3) *Class C*, given items that contain very small quantities of explosive material or items which burn slowly, if at all, under normal conditions. Generally, Class C items or materials are handled in standard approved shipping containers.

b. The DOD Classification was developed and is applied to explosives during manufacture, processing, and storage, as well as during transportation over public highways and railways. It provides twelve classes which are:

(1) *Class 1*, contains items which are fire hazardous only and are relatively safe in normal packing container, such as small arms, chlorates, powdered aluminum, safety fuses, fuse lighters, firing devices, explosive bellows, etc.

(2) *Class 2*, includes items of bulk smokeless powder, single base solid propellants, illuminants, igniters and tracer ele-

ments, signals, Group C and D chemical ammunition unassembled, etc.

(3) *Class 3*, includes rocket and JATO igniters, artillery primers, practice mines, packaged fuses, concussion type detonators, etc.

(4) *Class 4*, includes assembled chemical rockets, blank and saluting cannon ammunition, 20mm HE and HEI ammunition, Group A, B, C and D chemicals completely assembled in ammunition, etc.

(5) *Class 5*, includes projectiles loaded with Explosive D when not packaged with cartridge cases.

(6) *Class 6*, includes boosters, M-1 cable cutters, unpackaged fuses, and some fused mines.

(7) *Class 8*, includes blasting caps, detonators, primers and other percussion type elements.

(8) *Class 9*, includes bulk HE such as Comp. A, B and C, TNT, Tetryl, RDX, certain double base propellants, primary explosives, and numerous other items that may be expected to explode en masse at high order.

(9) *Class 10*, includes HE loaded bombs; fixed, semi-fixed and separate loading ammunition other than Explosive D, Comp. B, TNT and Amatol; HE loaded mines and grenades; HE rocket, complete rounds; HE warheads and other similar items.

(10) *Class 11*, includes ammunition-type items not considered an explosive hazard such as chemical ammunition not assembled with explosives.

(11) *Class 12*, includes items relatively insensitive that can be detonated only by very strong initiation such as wet nitrocellulose, DNT, and ammonium nitrate.

Note: The above listed items are representive only and do not include all in any one class.

It is to be recognized that factors such as container, whether item is assembled to other components, etc. affect its classification. An item may be in one class while in one condition, yet fall in another under different conditions. A good example is that of 0.0075 inch web thickness 20 percent NG double base propellant which is Class 2A when in metal lined wooden shipping boxes, but goes to Class 9 when stored in all metal boxes. Another example is WP loaded rocket heads which are Class 2, unless assembled to explosive components in which case they fall in Class 4. Again, JATO and rocket motors composed of Class 2 propellant only are Class 2 items, however, if Class 9 propellant is added to the manufacture composition, the items become Class 9.

5-4. Compatibility of Explosives.

a. When the hazards of explosive components or complete items are increased in the presence of others, the two are said to be incompatible. This fact is one of major importance in explosive manufacturing and processing plants, also in the storage of the materials and items. For standardization purposes, explosive items are divided into categories and assigned alphabetical groups, A through Q. All explosive(s) items are placed in one of these 17 groups, according to their characteristics or properties. Chapter 4, AFM 32-6, November 1961, provides a list of items in Air Force inventory included in each group.

b. Compatibility of items in storage is essential if incidents and explosions are to

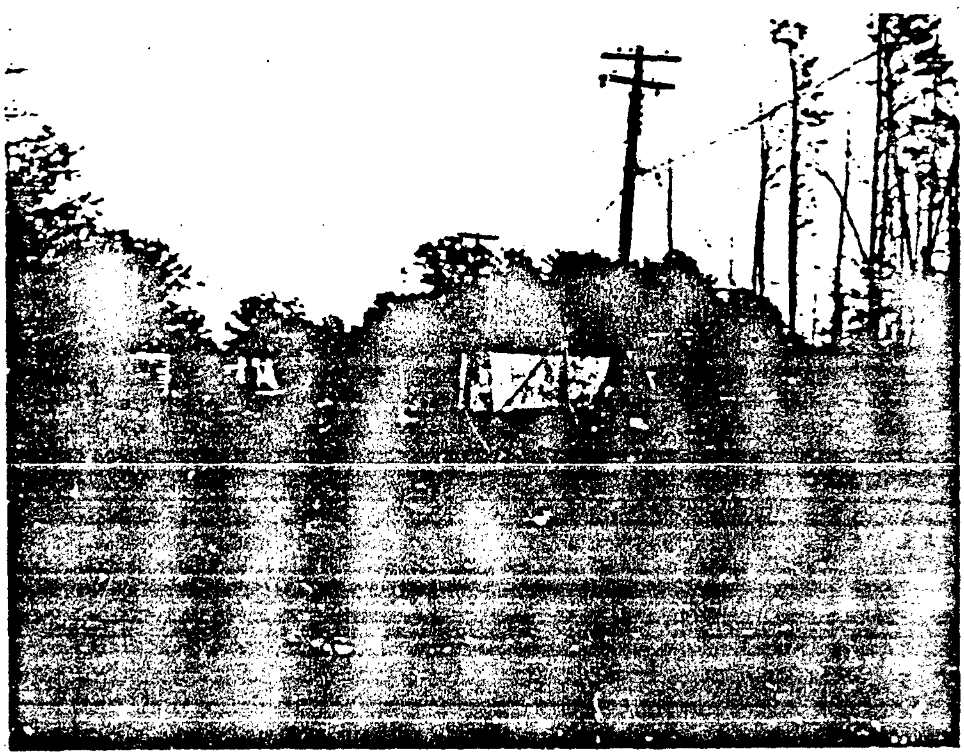
LESS THAN 1000 LBS. OF EXPLOSIVES DEMOLISHED THIS EARTH COVERED IGLOO.

be avoided. Failure to observe this precaution has been the source of major explosions one of which in recent years cost a DOD activity one fatality, multiple personal injuries and property damage exceeding $2,500,000.

5-5. Barricades: A barricade in munitions terminology is either a natural or artificial barrier between two explosive sites, or between one explosive site and nearby buildings. Its object is to limit in a prescribed manner the damage from an explosion at one site on the other site. To accomplish this objective, certain requirements must be met, for example:

a. Barricades must be sufficiently substantial to resist the shock wave, blast effect, and absorb missiles produced by the quantity of explosive involved. Such protection requires a natural hill or dirt mound, or heavy, thick, deeply anchored artificial structure.

b. The barricade must be sufficiently near explosive site to afford protection within a 30° angle from explosive mass center, thus height of barricade will vary in proportion to its distance from explosive mass, but in every case it must be at least higher than the highest point of explosive. No barrier less than three feet thick at its highest point will suffice. Generally, barricades should be located as near to the explosive site as practical, but not nearer than four feet to edge of the nearest explosive stack. This separa-



DEBRIS AND RUBBLE FROM EARTH COVERED STRUCTURE DEMOLISHED BY EXPLOSION RESULTING FROM INCOMPATIBLE STORAGE. NOTE REMAINS OF 12" CONCRETE WALLS IN BACKGROUND THROUGH TREES. RUBBLE IN STREET IS PRINCIPALLY FRAGMENTED CONCRETE.

tion gives venting space in event of explosion.

c. Barricades are commonly used to shorten distance requirements between two explosive buildings or sites, and occasionally are used to give additional protection for especially hazardous operations. They will not be used to reduce distances where fire hazardous materials are involved; for example, Class 2 materials and items. They will not be used to lessen distance of Class 9 materials from off-site exposures when quantities exceed 250,000 lbs.

5-6. Electrical Equipment for Hazardous Locations.

a. Experience and experiments have conclusively demonstrated that the arcing of conventional electric motors, switches, broken light bulbs, and shorted exposed wiring can ignite flammable/explosive laden atmospheres under proper conditions. Such atmospheres are common in rooms or bays where mixing, pressing, casting, cutting, machining, etc. of propellants and explosives take place. Ingredient handling and processing in rooms where alcohol, acetone and ether are mixed and pumped, and rooms where oxidizers are pulverized and screened produce flammable/explosive atmospheres. To prevent electrical facilities serving as an ignition source in such locations, special equipment has been designed, tested and proved, and is designated "explosion-proof." Such equipment is designed for specific hazardous areas and is so indicated by label marking on the equipment. Hazardous areas have been divided into *three classes* with appropriate subdivisions therein referred to as *groups*.

(1) *Class I* equipment is for use in areas where the hazard exists in form of a gas, vapor or fume. Under this class are subdivisions Group A, Group B, Group C and Group D. Explosives operations may involve all three groups.

(2) *Class II* equipment is for use in areas where hazard is in form of dust. Subdivision are Group E, Group F, and Group G. From the explosives standpoint, we are interested only in Group E which is for atmospheres containing explosive metal dusts such as: aluminum, magnesium, zirconium, Beryllium, sodium, lithium, chlorates, perchlorates and certain oxides.

(3) *Class III* is for use in atmospheres where explosive fiberous materials are suspended in air such as found in yarn mills.

b. Explosive requirements are normally satisfied by Class I and Class II equipment when appropriate groups are considered. Atmospheres containing flammable/explosive vapors of alcohol, acetone, etc., are satisfied by Class I, Group D, while atmospheres containing ether, ethylene and trimethylene require Class I, Group C. Atmospheres containing hydrogen gas necessitate Class I, Group B equipment. Acetylene atmospheres require Class I, Group A equipment.

c. When the principal hazard involved is dust, Class II, Group E is appropriate. When both dust and vapors or fumes are present, equipment approved for both exposures is required; for example Class I, Group C or D, and Class II, Groups E and F. Such equipment is available for most jobs; however, the cost is approximately 5 to 1 over conventional equipment. Equipment for Class I, Groups B and A exposure is difficult to obtain and quite expensive therefore, where exposure warrants Class I, Groups A and B fixtures, indirect lighting and power sources are utilized. In some cases pneumatic oil driven motors are substituted for electric motors. An alternate method substituted for approved items on rare occasions is to totally enclose or "house-in" equipment, and provide positive pressure inside closure with an inert gas. The Air Force does not approve of such contrivances. AFM 32-6 cites the National Electrical Code as the authority for electrical equipment in hazardous location on Air Force installations. Articles 500-510 of the Code discuss such equipment.

5-7. Static Electricity.

a. The danger of static electricity acting as an ignition source was a controversial subject for many years but now, is a generally accepted fact. The acceptance of this fact has resulted from cause findings in the investigations of fires and explosions occurring in explosive plants, hospital surgical rooms and the chemicals industry. It has lead to the establishment of static dissipation measures either by grounding or humidity control. "The generation of static electricity is not of itself a hazard. The hazard arises when static is allowed to accumulate, for subsequently it may discharge as a spark across an air gap in the presence of highly flammable material, and thus produce a source of ignition." (Note: AFM 32-6.)

b. Static electricity is generated when two poor, or nonconductors are brought together then separated. Liquids, particularly hydrocarbon base solvents, generate static when they flow through rubber piping: the movement of rubber belting over rapidly turning pulleys creates static and the contact and separation of synthetic fibers is a highly generative method. Clothing of synthetic materials rubbing against a person's body as he moves generates static also.

e. All are familiar with the shock experienced after sliding over nylon or rayon seat covers in an automobile then quickly touching a grounded object. Most people are also aware that the shock is more intense on a dry windy day and that on a rainy day no shock may be felt.

d. Many factors affect the static voltage output such as the conductivity of materials, air humidity and rate of materials movement. Tests have shown that rapid flow of petroleum products through a 2 in. synthetic rubber hose can produce static of several thousand volts. The movement of ones body when wearing nylon clothing in a dry room creates static charges of several hundred volts. If the moisture is raised the voltage drops, and if the clothing is changed to cotton it becomes practically nonexistent

e. Static is dissipated or bled-off to ground through conductors or through moisture in air. If allowed to build up then arc to ground, high temperature and flame are momentarily produced which can ignite highly sensitive materials. There are numerous cases where this has happened.

f. This phenomena has led to the standard practice of grounding all piping, belting and machinery, etc., where dangerous atmospheres may develop. Many operations are additionally protected by use of conductive flooring, and providing workers with conductive sole shoes.

5-8. Nonsparking Tools.

a. Sparks generated by the striking of ferrous tools against concrete or against steel machinery, piping, etc., not only possess flame but high temperatures also. Although these flames and high temperatures are of momentary duration their action can be compared somewhat to that of a sparkplug in a flammable/explosive atmosphere. To prevent sparks of this nature, tools possessing nonsparking properties are employed around exposed explosives and in explosive laden atmospheres.

b. The term "nonsparking" is controversial and can be misleading. For one thing most metals hard enough to serve as tools can be made to throw off red-hot particles if held long enough against a high speed grinding wheel. These are not true arcs from friction but heated particles worn away by grinding. Only tools made of high carbon content steel will consistently produce sparks when in normal use by workers. These should not be used in the presence of open explosives. Other tools with satisfactory strength and rigidity properties are available for work in such areas which offer minimum sparking potentials. Among such tools are beryllium alloys, alluminum, magnesium and nickel alloys, and alloy combinations such as K-Monel.

c. Scrapers, puddlers, dippers, and similar tools made of plastic, teflon, aluminum, copper, etc., are often satisfactory for purposes they serve. It is recognized that these may not be true nonsparking in a technical sense: however the potential of a spark from such tools in the hands of a careful worker, being of such magnitude as to create a hazard is so remote as to be inconsequential.

d. There are methods for safe use of spark producing tools in emergency situations where hazardous atmospheres cannot be cleared. Examples of known cases satisfactorily handled under emergency conditions are:

(1) A ruptured steel pipe required cutting, threading and splicing. Conventional pipe tools were used with stream of water flowing on cutter and threading dies. One case required large Stillson wrench on coupling nuts—Conventional wrench was employed while stream of water flowed over nuts.

(2) In one case a broken gasoline line under concrete allowed gasoline to saturate earth and penetrate concrete joints. A dike was built around the area, filled to three inches of water and jack hammer used to break concrete.

Such measures as above should be resorted to only when emergency circumstances such as leaks develop and area cannot be purged, and *special nonsparking tools* required for safety are not available.

Chapter VI

AMMUNITION AND EXPLOSIVES DISPOSAL

6-1. Reconditioning Or Destruction of Ammunition and Explosives.

The nature, characteristics and quantity are normally the governing factors in establishing methods for either the reconditioning or destruction of ammunition and explosives. In many cases it is desirable to recover or salvage items, components, etc., which have further use and value. For example, the brass and other metal recoverable from cartridge cases has appreciable value. Shell and bomb cases are often reclaimed and, occasionally, high explosives such as TNT may be melted out of shells and bombs, reworked and used again. Solid propellants are often reworked and placed in service again.

a. Reworking of munitions and explosives generally requires specific buildings, tooling and facilities, for the processes involved are neither simple nor safe. Barricading, shielding, and remote controls are generally employed; quantities are restricted; and carefully developed step-by-step procedures are followed. Programs for the rework of munitions should be carefully developed, facilities engineered for the individual operation, and carried out under the supervision of a technical specialist.

b. Sites and methods for explosives destruction should be carefully selected and evaluated. In no case should sites be selected within 1800 feet of other operations or inhabited buildings and then only if pits or similar aids are used to limit misile dispersal. Normally, the distance between destruction sites and other activities, operations, etc., should be a minimum of 2400 feet, particularly if materials may be expected to detonate and generate a shock wave and produce missiles.

c. Destruction sites are generally of two types; one for materials that normally burn (burning ground) or deflagrate at worst, and one for materials that may be expected to detonate (demolition area) or go high order such as Class 9 or 10 materials. When there exists the necessity for both types of destruction sites, they should be located a minimum of 2400 feet apart if they are to be operated concurrently. If they are to be operated alternately, the distance may be reduced to unbarricaded missile distance.

d. Different type materials require different destruction and disposal methods. Normally, black powder and most pyrotechnic materials can be leached out and destroyed by water. Large quantities are frequently burned; however, burning is a hazardous operation that requires special care and extreme caution.

e. Solid propellants, both "nitro" and composite types, are usually destroyed by burning. Bulk high explosives such as NG, TNT, nitrated gelatin and nitrostarch are generally spread on wet excelsior or paper in open pits and burned. Ignition of such materials is done remotely by using a slow burning fuse or electric squib.

f. Items that are to be destroyed by detonation, or that normally do not burn but go high order, should be placed in pits and covered with dirt. The operator initiates destruction from his protective shelter using an electric blasting cap or detonator.

g. Burning and demolition grounds should be kept clear of free flammable material such as paper, grass and wood rubbish. Areas should be provided with plenty of water and fire hose, fire extinguishers, telephone service, emergency first aid items, and in some cases fire trucks and ambulances. Areas should be fenced, placarded and admission thereto controlled. It is also desirable to have a magazine or other suitable storage facility nearby (appropriate Q-D) to store materials and items awaiting destruction. Only alert well trained operators under qualified supervision should be permitted to work at burning and demolition grounds.

h. Liquid propellants are frequently destroyed by burning, sometimes by chemical decomposition and, in some cases where distance and soil formation permit, by burying. Some ingredients and waste products are highly toxic, water contaminants, will not burn, explode, nor chemically decompose easily. They pose special disposal problem and may require burial at sea.

6-2. Special Material Destruction. In summary, most explosives and propellants can be successfully and safely destroyed either by burning or demolition. Small quantities of special materials may be destroyed or neutralized chemically. A few materials in large quantities require burial at sea. Technical guidance is available for personnel required to deal with special or abnormal materials.

Chapter VII

BASIC SAFETY REQUIREMENTS FOR OPERATIONS AND PRACTICES WHERE EXPLOSIVES ARE INVOLVED

7-1. Explosives sites, operations, and storage should be enclosed in climb-proof fences with placards conspicuously posted on fence to warn of danger. Entrance gates should be either locked or manned.

7-2. Smoking within explosive areas should be permitted only at designated rigidly controlled points. Smoking areas should be equipped with electric or similar type lighters, water contained butt cans, fire extinguishers, and properly policed at all times.

7-3. Matches, lighters, and other spark producing items should not be permitted in explosive buildings except when approved in writing by the fire and safety departments.

7-4. Repair or maintenance work on explosives buildings or equipment should not be permitted until a work permit signed by the building supervisor and safety department is issued. The permit should state special precautions, protective devices, and restrictions necessary.

7-5. Explosive buildings should be constructed of flame resistant materials, inner wall finishes should not absorb or trap explosive vapors or dusts.

7-6. Buildings housing explosives or explosive operations should be provided with lightning protection.

7-7. Electric lights, switches, motor, and other arcing electrical appliances used in the presence of, or near, exposed explosives should be explosion-proof.

7-8. All metal processing machinery and equipment around explosives should be grounded. The used of nonconductive static producing tools and equipment should be avoided whenever static sensitive materials are in an exposed state.

RESULTS OF FIRE WHEN ROCKET MOTOR IGNITED AND BURNED DURING SAWING OPERATION. SAWS WERE SPECIAL STEEL ALLOYS BUT PARTS EXPOSED TO MOTOR BURNED TO DUST. A DELUGE SYSTEM WOULD HAVE MINIMIZED $100,000 LOSS.

7-9. Explosive bays employing strong walls (12" or more of reinforced concrete) should have one weak wall and blow-off type roof to quickly release pressure in event of explosion.

7-10. All above ground piping such as gas, air, water, and steam which enters explosives buildings should be grounded outside buildings.

7-11. Exhaust system piping should have smooth inner surfaces and be designed to avoid the build up of dusts and vapors within the piping. Forced draft by jet principle employing non-return baffles should be employed when practicable.

7-12. Air conditioning and circulating equipment of the closed system type will be designed to prevent recirculation of explosive contaminated air, or the entrapment of explosives in the system.

7-13. Overhead positive feed hot air is the preferred type of heat for explosive rooms or bays. When radiators are used, steam pressure should not exceed 5 psi.

7-14. Bays and rooms in which explosives are processed should be equipped with quick acting water deluge systems except when materials are reactive with water such as lithium hydride.

7-15. Self acting machinery and devices performing operations on critical or extremely sensitive materials should be equipped with three separate automatic cutoff controls.

7-16. All doors to explosive bays should open outward and be equipped with quick opening releases (anti-panic hardware) to permit rapid exit in emergency.

7-17. Hazardous operations should be kept separated with adequate protection between, either by distance, barricades, operational shields, or walls, as appropriate.

7-18. Electric service lines of all types to explosive buildings should be run underground from a point at least 50 feet away from the building.

7-19. All electric overhead power lines carrying 15,000 volts or more should be located at least 200 feet from explosive buildings.

7-20 Both primary and secondary overhead power transmission lines carrying less than 15,000 volts should be located at least 50 feet away from any explosives building.

7-21. Extremely hazardous operations such as propellant mixing, extrusion, somo casting, and machining of propellant grains should be performed by remote control with operators houses in protective bunkers equipped with controls and closed circuit TVs, or other satisfactory viewing means.

7-22. Aisles and passageways should be kept free of any impediment that offer delay to quick exit in event of emergency.

7-23. Motorized equipment employed for handling explosives should meet all requirements established in AFM 32-6 and T.O. 11 A-1-40.

7-24. All operators of motorized materials handling equipment carrying explosives should be specially trained and licensed.

7-25. Explosives handling equipment such as trucks, trailers, tow-tractors, side loaders, fork lifts, hoists and cranes should be visually checked daily, and should be removed from service when abnormalities involving safe operation are discovered.

7-26. Dead end roads to explosive buildings should be avoided.

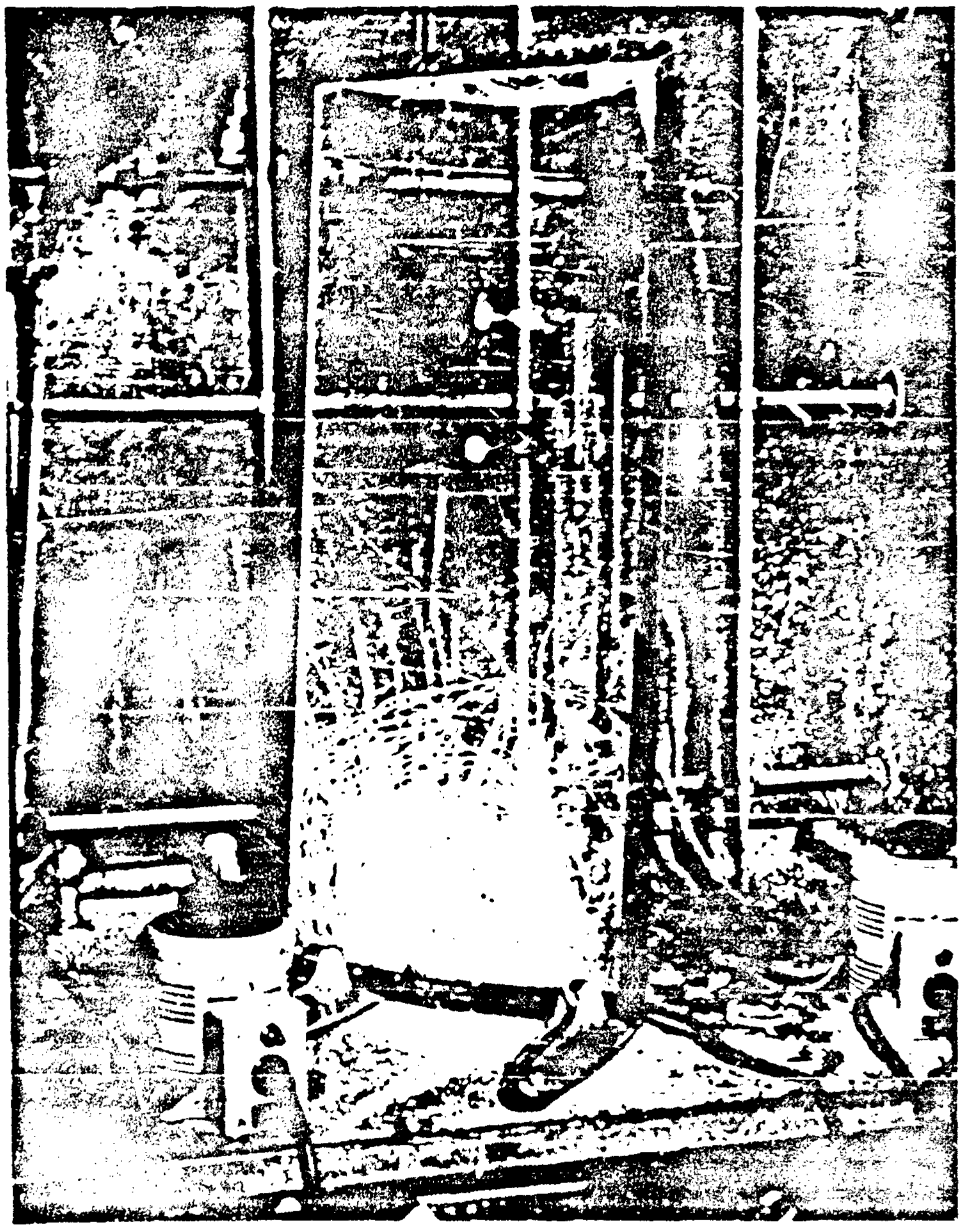
7-27. Nonsparking tools are essential for safety when working in the presence of flammable/explosive dust or vapor atmospheres. They are not necessary when working closed packaged items, or when dusts or vapors are not present. Normally, cured finished items do not release sufficient fumes, vapors, or dust to build up explosive atmospheres.

7-28. Protective shields, barriers, and remote control stations should be utilized to the maximum practical degree.

7-29. Good housekeeping is of utmost importance — scrap explosives should be promptly collected as it develops and moved to an appropriate storage point. Explosive waste collecting cans should be partially filled with water (unless scrap is reactive in presence of moisture) and kept closed.

7-30. Explosive items should not be tossed, dropped, bumped or otherwise roughly handled.

7-31. A well organized, staffed and supervised, maintenance and cleanup program should function constantly.



THIS SHIELD OF 1/2" SAFETY GLASS PROTECTED OPERATOR FROM INJURY WHEN 10 GRAMS OF EXPERIMENTAL MATERIAL ON WHICH HE WAS WORKING EXPLODED.

7-32. Improvised tools, platforms, and other operational devices should not be permitted.

7-33. Practices and control techniques should be established and rigidly adhered to, which promptly account for all tools and devices which might enter processing equipment and create a hazard.

7-34. Racks, bins, cabinets, or shelves should be provided for storage of hand tools when not in use.

7-35. Explosive quantities within a building, bay, or at a work site, should be limited to that essential for an efficient operation and in no case should quantity exceed an 8-hour supply.

7-36. Personnel and explosive limits placards should be posted in a conspicuous place in each operating bay.

7-37. Established procedures should be developed for hazardous operations and workers thoroughly indoctrinated in each detail. Established procedures should be readily available at work site at all times.

7-38. Each person involved in explosive work should be thoroughly trained for job; know hazardous properties of materials; how to guard against hazards; emergency procedures; and should be adequately supervised to assure observance of precautions.

7-39. Workers should not be assigned to work alone when performing hazardous jobs. A fellow worker should be nearby to give assistance in event of emergency.

7-40. Employees' clothing should be suitable for the hazards; for example, employees working with open explosives as in mixing, grinding, machining, etc., which produce flammable/explosive vapor or dusts should be provided flame resistant coveralls, head coverings and nonsparking or conductive sole shoes.

7-41. Necessary personal protective equipment such as respirators, gloves, face shields, aprons, and shoes should be provided and workers required to use them.

7-42. Showers and change houses should be provided for workers employed in explosive or hazardous materials areas. Personal effects and clothing not in actual use should be left in change houses.

7-43. Jewelry, such as bracelets, necklaces, ear rings, key chains, wrist watches and finger rings containing sets should not be worn while working with explosives.

7-44. Loose-fitting garments such as open jackets, dangling sleeves, and flowing ties should not be worn around explosives machinery.

7-45. Lattice type pockets and cuffless trousers should be worn where open explosives are present to avoid entrapment of explosives in clothing.

7-46. A sound program should be in effect to guard against ill effects to health of employees from toxic properties of explosive ingredients. Such a program should provide for physical examinations, showers, change house facilities, frequent change of clothing, cleaning and sterilization of protective equipment, industrial hygiene studies and other measures necessitated by nature of work and properties of materials.

7-47. Employees working where radiation hazards may be present should be provided film badges or other approved exposure recording devices.

7-48. Incompatable chemicals or materials that may spontaneously react in association with each other must be kept separated except in operational processes where controls are provided.

7-49. Well developed emergency plans should be in effect, and trial runs practiced frequently enough to assure that each employee knows what to do in case of emergency.

7-50. Regularly conducted safety meetings should be held with all employees to maintain a high level of interest. Many plants effectively use the supervisor's weekly "stand up safety meeting" of 5-10 minutes to discuss pertinent safety matters.

PROPERLY ATTIRED EXPLOSIVE OPERATOR AT CONTROL PANEL FOR RE-MOTELY OPERATED MIXER. NOTE CLEAN FLAME PROOF CAP, GLOVES, POCKET-LESS, CUFFLESS COVERALLS, EYE PROTECTION AND CONDUCTIVE SOLE SHOES.

ALL THAT REMAINS OF A $100,000 ROCKET MOTOR THAT FAILED UNDER STATIC TEST. STRONG WALLS AND BARRICADES PROTECTED OUTLYING STRUCTURES AND OPERATIONAL PERSONNEL.

CHRONOLOGY OF EXPLOSIVES DEVELOPMENTS AND EVENTS

660	Greeks used "Greek Fire" in a flame throwing device.
1000	Chinese used pyrotechnic devices for amusement.
1250	Roger Bacon described ingredients and formula for black powder.
1300	Berthold Schwarz invented a gun and propelled stones from it with black powder.
1425	Black powder was granulated, enabling more standardized performance.
1525	The process of screening granulated powder began.
1838	Pelouze prepared nitrocellulose by nitrating paper.
1846	Sobrero prepared nitroglycerin and described it as an explosive.
1863	Nobel began commercial preparation of nitroglycerin.
1864	Schultze made first successful smokeless powder.
1865	Abel purified and stabilized nitrocellulose.
1867	Nobel developed dynamite.
1868	E. A. Brown began series of developments that resulted in principle of booster-explosive.
1875	Nobel developed blasting gelatin.
1884	Vieille invented Poudre B, first satisfactory smokeless powder for rifled guns.
1886	Turpin patented use of picric acid as a bursting charge for shells. Used by the French under name of melinite, and by the British under name of lyddite.
1888	Nobel invented double-base propellant powder.
1889	Kellner and Abel developed cordite.
1898	U. S. Navy began manufacture of smokeless powder as gun propellant.
1900	U. S. Army began manufacture of smokeless powder as gun propellant.
1901	Vignon and Gerin prepared and tested PETN.
1902	Germany began to use TNT as bursting charge for shells.
1909	Diphenylamine was introduced as a stabilizer for smokeless powder.
1910	Ammonium picrate was adopted by U. S. as bursting charge for armor-piercing shells.
1918–1919	Lead azide was used as initiator, tetryl as a booster, and amatol as a bursting charge.
1926	Goddard successfully fired first liquid-fueled rocket.
1920–1945	RDX, Composition A, B, and C, PETN, DEGN, lead styphnate, NQ Picratol, Haleite, Tetrytol, Tetracene, Tritonal Pentolite, Torpex and other explosives were developed; also, the shaped charge principle.
1942–1944	German scientists developed and fired V-1 and V-2 rocket missiles.
1940–1945	Development and use of small rockets by Army and Navy.
1950–1955	Short range missiles were developed with study on intermediate to intercontinental.
1950–1960	Age of intense effort in development of solid and liquid rocket motors.
1957	Space age began with first earth orbiting satellite.
1958–1960	Outer space vehicle development.
1960	First orbital manned flight around world.

NOTE: Early dates are only approximate as various writers have given different dates.

CHRONOLOGY OF EXPLOSIONS

The following is a list of dates and locations of some explosions that have occurred involving large quantities of materials. No attempt has been made to list the hundreds of smaller ones which have accounted for thousands of lives and unaccountable property losses.

DATE	LOCATION	Quantity of Explosive (lbs.)	Remarks
1769	Brescia, Italy	175,000	Black powder in storage
Aug 1886	Chicago, Ill.	162,000	Dynamite and black powder in storage
Feb 1896	Johannesburg, South Africa	110,000	Gelatin dynamite in storage
Apr 1891	Rome, Italy	570,000	Black powder in storage
July 19[illegible]	Highland Station, Calif.	398,415	Dynamite & black powder
Sept 1905	Fairchance, Pa.	135,000	Dynamite and black powder in storage
Oct 1907	Fontanet, Ind.	875,000	Black powder in storage
Mar 1908	Batuco, Chile	352,000	Black powder in storage
Apr 1910	Kobe, Japan	301,550	Dynamite and Gelignite
Mar 1911	Pleasant Prairie, Wisconsin	2,311,650	Dynamite & black powder
Jan 1913	Vancouver, British Columbia	124,530	Hauling dynamite
Mar 1913	Baltimore, Md.	600,000	Dynamite on ship
Aug 1913	San Antonio, Spain	103,000	Gelatin dynamite
July 1916	Black Tom Island, New York	500,000	TNT and picric acid on barges in freight cars
Jan 1917	Haskell, N. J.	288,534	Nitroglycerin cannon powder
Apr 1917	Eddystone, Pa.	?	133 killed
June 1917	Steinfield, Germany	5,500,000	Explosives
Dec 1917	Halifax, Nova Scotia	5,234,751	TNT, Picric acid and guncotton on 3 ships
July 1918	Split Rock, New York	—	50 killed
Sept 1921	Oppan, Germany	9,000,000	Manufacturing plant—mixtures of ammonium nitrate and ammonium sulphate
Sept 1922	Falconara, Italy	3,360,000	Explosives

DATE	LOCATION	Quantity of Explosive (lbs.)	Remarks
Oct 1921	Manila, P. I.	316,000	TNT, dynamite and black powder
July 1926	Lake Denmark, N. J.	2,380,000	30 killed—TNT and other explosives
Sept 1927	Witkowicz, Poland	1,500,000	Explosives powder in storage
Sept 1940	Kenvil, N. J.	—	49 killed
Mar 1942	Burlington, Iowa	—	22 killed, high explosive
June 1942	Elwood, Illinois	—	51 killed, HE loaded items
Apr 1944	Bombay, India	2,000,000	High explosives on ships—unknown dead
July 1944	Port Chicago, Calif.	3,500,000	Loading ships with ammunition—320 killed
Nov 1944	Burton-on-Trent, England	5,340,000	Explosives in storage
Nov 1944	Pacific (Mount Hood)	5,300,000	Explosives on ships—unknown dead
Dec 1944	Soisoons, France	6,000,000	Mixed explosives on freight cars
Apr 1947	Texas City, Texas	5,600,000	2 ships ammonium nitrate—468 killed
Jan 1948	Savanna, Ill.	294,000	High explosives in storage
July 1948	Kingsport, Tenn.	840,000	Nitramon-Quarry blasting
May 1950	South Amboy, N. J.	840,000	Dynamite and other explosives in railroad cars—31 killed
Mar 1953	Lewis, Indiana	241,000	Ammunition in rail transit
July 1960	Indian Head, Md.	165,000	Solid propellant and propellant ingredients

The National Fire Protection Association has a listing of 2952 persons killed in accidental explosions from 1930-1952 but states this number is only about 10% of total estimated dead from explosions during this 23 year period.